EUROPEAN
MATERIALS RESEARCH SOCIETY

**Strasbourg (France)**

# E-MRS Spring Meeting 2004

May 24-28, 2004

# SYMPOSIUM A2

## Nanophotonic materials


Symposium Organizers:

Albert Polman, FOM, Amsterdam, The Netherlands

Henri Lezec, Louis Pasteur University, Strasbourg, France

Harry A. Atwater, CALTECH, USA



Symposium Support:

We wish to thank the following for their contribution to the success of this conference:

EOARD

European Office of Aerospace Research and Development of the USAF

# REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188



**1. REPORT DATE *(DD-MM-YYYY)***
21-11-2005

**2. REPORT TYPE**
Conference Proceedings

**3. DATES COVERED** *(From – To)*
24 May 2004 - 28 May 2004

**4. TITLE AND SUBTITLE**
E-MRS Spring Meeting - Nanophotonic Materials Session

**5a. CONTRACT NUMBER**
FA8655-04-1-5025

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**
Conference Committee

**5d. PROJECT NUMBER**

**5d. TASK NUMBER**

**5e. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Université Louis Pasteur
BP 70028
Strasbourg Cedex 67083
France

**8. PERFORMING ORGANIZATION REPORT NUMBER**
N/A

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
EOARD
PSC 802 BOX 14
FPO 09499-0014

**10. SPONSOR/MONITOR'S ACRONYM(S)**

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**
CSP 04-5025

**12. DISTRIBUTION/AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited. (approval given by local Public Affairs Office)

**13. SUPPLEMENTARY NOTES**
Abstracts at web site
http://www-emrs.c-strasbourg.fr/2004_SPRING/MINIPROG/MINIA2.pdf

**14. ABSTRACT**

The Final Proceedings for E-MRS Spring Meeting - Nanophotonic Materials Session, 24 May 2004 - 28 May 2004

This is an interdisciplinary conference. Topics include Surface plasmon optics in thin films, Nanoparticle plasmonic structures, Nanocrystal and nanowire lasers and LEDs, Molecular scale photonics, Nanophotonic mechanisms for waveguiding in and light extraction from optoelectronic devices, Subwavelength scale imaging and pattern transfer, Lithographic and nonlithographic fabrication methods for nanophotonic materials, Computational methods for nanophotonic materials and devices, Negative index and left-handed materials, Nanophotonic materials for sensors, Materials and structures for inhibited/enhanced optical emission, Integration of nanophotonic materials and devices with microphotonics (e.g., photonic crystal devices and other monolithic integrated photonic technologies), Subwavelength scale photonics at non-optical (infrared, microwave) frequencies.

**15. SUBJECT TERMS**
EOARD, Sensor Technology, Microelectronics, Nanotechnology, optical materials

| 16. SECURITY CLASSIFICATION OF: a. REPORT | b. ABSTRACT | c. THIS PAGE | 17. LIMITATION OF ABSTRACT | 18, NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| UNCLAS | UNCLAS | UNCLAS | UL | N/A (web site) | DONALD J SMITH |
| | | | | | **19b. TELEPHONE NUMBER** *(Include area code)* +44 (0)20 7514 4953 |

**Standard Form 298** (Rev. 8/98)
Prescribed by ANSI Std. Z39-18

# E-MRS 2004 SPRING MEETING

# SYMPOSIUM A2

## Thursday, May 27, 2004 Morning

Joint Session Symposium A1, A2: Silicon-based nanophotonics
Session chairs: P. Fauchet (University of Rochester, NY, USA)
and P. Polman (FOM-Institute AMOLF, Amsterdam, The Netherlands)

**A1-A2/01** 08:30 -Invited-

NANOENERGETICS, NANOMATERIALS, NANODEVICES, NANOCOMPUTING - PUTTING THE PIECES TOGETHER

**G. Bourianoff**, Intel Corporation, USA

The enormous growth of the communication industry has increased the demand for new photonic functionality at a low cost. For this purpose, it would be highly desirable to have light sources, waveguides, amplifiers, and detectors that are monolithically fabricated on Si with CMOS technology. The materials used in current CMOS integrated circuit technologies are chosen to optimize electronic performance. However, upon closer examination these materials are also suitable for producing, manipulating, and detecting optical signals. The unique properties of Si nanostructures such as nanoparticles and nanowires can be exploited to fabricate Si-based light sources and detectors. $SiO_2$ can be used to fabricate highly transparent optical waveguides and high Q micro-disk resonators. Metallic interconnects can serve as plasmonic waveguides that guide electromagnetic waves at optical frequency (“light”) below the diffraction limit.

To evaluate the use of deep submicron CMOS technology as a fabrication platform for integrated nanophotonic and plasmonic devices, our group is developing a laboratory-on-a-chip environment. On this platform we are fabricating and testing light emitting Si nanostructures, CMOS image sensors utilizing subwavelength metallic nanostructures, and plasmonic devices. Optical techniques, including scanning near-field optical microscopy are used to investigate the unique properties of these devices and study the fundamentals of light-matter interactions at the nanoscale.

**A1-A2/02** 09:00 -Invited-

TOWARDS CMOS COMPATIBLE NANOPHOTONICS

**M.L. Brongersma**, Stanford University, Geballe Laboratory for Advanced Materials, 476 Lomita Mall, Stanford CA 94305, USA

**A1-A2/03** 09:30 -Invited-

PHOTONIC CRYSTALS BASED ON MACROPOROUS SILICON

**U. Gösele**, S. Matthias and F. Müller, Max-Planck-Institut für Mikrostrukturphysik, Experimentelle Abteilung II, Weinberg 2, 06120 Halle/Saale, Germany

An overview on 2-dim and 3-dim photonic crystals will be given based on electrochemical etching of silicon. It will be shown how new breakthroughs in electrochemical etching may also allow fabrication of large-scale 3-dim photonic crystals with a complete photonic band gap. A comparison with other techniques to fabricate photonic crystals will be given and various potential applications will be discussed.

**A1-A2/04** 10:00 -Invited-

Si-BASED NANOPHOTONICS

**S. Coffa**, ST Microelectronics, Catania, Italy

10:30 **BREAK**

## Session I: Surface plasmons 1
## Session chair: H. Lezec (Louis Pasteur University, Strasbourg, France)

**A2-I.1** 11:00 -Invited-

NANO-COMPONENTS FOR PLASMONICS

**J.R. Krenn**, H. Ditlbacher, A. Hohenau, A. Stepanov, A. Leitner, F.R. Aussenegg, Institute for Experimental Physics and Erwin Schroedinger Institute for Nanoscale Research, Karl-Franzens-University Graz, A-8010 Graz, Austria

The miniaturization of photonic devices towards nanoscale dimensions meets two major difficulties. First, light fields in conventional optics are essentially three-dimensional, inhibiting the realization of highly integrated planar devices in analogy to microelectronics technology. Second, diffraction restricts the minimum lateral size of dielectric optical elements and waveguides to about half the effective light wavelength. Recent results demonstrate that optics based on surface plasmons (SPs) allows to overcome both limitations. We discuss experimental results on the manipulation of SP propagation in lithographically nanostructured thin metal films, demonstrating two--dimensional counterparts of optical elements as mirrors and beamsplitters [1]. Important for interfacing SPs with conventional optics, the local light/SP coupling efficiency is quantified [2]. With regard to waveguiding we show how the SP dispersion relation in metal wires with nanoscale cross-section can be measured and that such wires can be used to propagate SPs [4].

[1] H.Ditlbacher, J.R.Krenn, G.Schider, A.Leitner, F.R.Aussenegg, Appl.Phys.Lett. 81, 1762 (2002)
[2] H.Ditlbacher, J.R.Krenn, A.Hohenau, A.Leitner, F.R.Aussenegg, Appl.Phys.Lett. 83, 3665 (2003)
[3] G.Schider, J.R.Krenn, A.Hohenau, H.Ditlbacher, A.Leitner, F.R.Aussenegg, W.L.Schaich, I.Puscasu, B.Monacelli, G.Boreman, Phys.Rev.B 68, 155427 (2003)
[4] J.R.Krenn, B.Lamprecht, H.Ditlbacher, G.Schider, M.Salerno, A.Leitner, F.R.Aussenegg, Europhys.Lett. 60, 663 (2002)

**A2-I.2** 11:30

LAUNCHING AND DECOUPLING SURFACE PLASMONS VIA MICRO-GRATINGS

Eloïse Devaux and Thomas Ebbesen, Laboratoire des Nanostructures, ISIS, Université Louis Pasteur, BP 70028, 67083 Strasbourg, France, Jean-Claude Weeber and Alain Dereux Laboratoire de Physique, Optique Submicronique, Université de Bourgogne, BP 47870, 21078 Dijon, France

Controlling separately the launching of surface plasmons and their recovery as freely propagating light is essential for the development of surface plasmon photonic circuits. With this target in mind, we have studied in the near-field the launching of surface plasmons in a well-defined direction by micro-arrays of subwavelength holes milled in a thick metal film. We show that surface plasmons can then be converted back to freely propagating light by means of another appropriately designed array. These results not only provide insight into the efficient decoupling of surface plasmons but also into their role in the enhanced transmission mechanism.

**A2-I.3** 11:45

ADVANCES TOWARD DESIGN OF SUBWAVELENGTH PLASMONIC DEVICES

Luke A. Sweatlock(a), Jennifer A. Dionne(a), Joan J. Penninkhof(b), Albert Polman(b), Harry A. Atwater(a), (a)Caltech USA, (b)FOM AMOLF Inst., The Netherlands

Metal nanoparticles interact strongly with light at the frequency of a coherent electron oscillation, or plasmon, within the particle. Arranged in closely spaced arrays, in which the spacing is smaller than the wavelength, such particles interact via the electromagnetic near-field. Arrays exhibit collective plasmon modes, which may vary significantly from that of a single particle. A promising application is the construction of waveguides for visible or near-infrared frequencies.

We will discuss the properties of closely spaced chains of 10 nm Ag particles. We find via finite difference time domain (FDTD) simulation the mode spectrum as a function of spacing and of total array length. These results are compared to experimental far-field extinction of semi-ordered nanoparticle arrays of similar size, which we have fabricated by high energy ion irradiation of Ag-doped glass. The collective plasmon extinction peak can be shifted by more than 1 eV relative to the single particle resonance, and can be tuned throughout the technologically important visible and near-infrared spectrum. This large shift is related to strong interparticle coupling which cannot be achieved via conventional lithographic methods. We also investigate via FDTD the waveguiding properties of these nanoparticle arrays. By monitoring group velocity and attenuation we find that signals will decay at 1 dB per 4 particles, which is sufficient to allow design of device geometries involving several tens of nanocrystals. This represents a sixfold increase over the bandwidth of lithographically defined arrays. We will dicuss this and other implications for the development of a three-terminal subwavelength switching device, including various schemes to acheive modulation and gain.

**A2-I.4** 12:00

CHERENKOV RADIATION AND PLASMONIC EXCITATIONS IN PHOTONIC CRYSTALS

F.J. García de Abajo(a,b), A.G. Pattantyus-Abraham(c), N. Zabala(a,b), A. Rivacoba(a,b), M.O. Wolf(c) and P.M. Echenique(a,b), (a)Centro Mixto CSIC-UPV/EHU, Apartado 1072, 20080 San Sebastián, Spain, (b)Donostia International Physics Center (DIPC), Apartado 1072, 20080 San Sebastián, Spain, (c)Department of Chemistry, UBC, 2036 Main Mall, Vancouver, BC, V6T 1Z1, Canada

Electron energy loss spectroscopy (EELS) and light emission induced by fast electrons in electron microscopes are used to probe photonic structures ranging from isolated and clustered particles [1-3] to photonic crystals [4]. Some of the loss features are shown to be associated to the excitation of radiative modes in the samples (Cherenkov radiation), from where information on photonic bands is extracted. This is done both for 2D and 3D crystals. Comparison between theory and experiments performed on porous alumina crystals with ~100-nm lattice constant results in excellent agreement for a prominent Cherenkov feature at around 6-9 eV [4]. The features of the loss spectra are shown to be strongly correlated with the density of photonic states, suggesting the potential application of this technique to probe the quality and actual performance of photonic crystals. Plasmonic excitations in metalodielectric crystals and finite metallic systems are also analyzed, including combinations of recently realized nanorings [5]. The effective optical properties of various families of metamaterials formed by this type of structures will be explored and results for the dielectric constant and the magnetic permeability will be offered.

[1] F. J. García de Abajo and A. Howie, Phys. Rev. Lett. 80, 5180 (1998).
[2] N. Yamamoto, K. Araya, and F. J. García de Abajo, Phys. Rev. B 64, 205419 (2001).
[3] F. J. García de Abajo, Phys. Rev. Lett. 82, 2776 (1999).
[4] F. J. García de Abajo, N. Zabala, A. Rivacoba, A. G. Pattantyus-Abraham, M. O. Wolf, and P. M. Echenique, Phys. Rev. Lett. 91, 143902 (2003).
[5] J. Aizpurua, P. Hanarp, D. S. Sutherland, M. Käll, G. W. Bryant, and F. J. García de Abajo, Phys. Rev. Lett. 90, pp. 057401-1-4, 2003.

**A2-I.5** 12:15

EXTRAORDINARY TRANSMISSION OF THZ RADIATION THROUGH SUBWAVELENGTH APERTURES IN SEMICONDUCTOR GRATINGS

J. Gómez Rivas, P. Haring Bolivar, C. Janke and H. Kurz, Institut für Halbleitertechniek, RWTH Aachen, Sommerfeldstrasse 24, 52074 Aachen, Germany

The fascinating discovery of the enhanced transmission of light through thin-metal gratings of nano-holes has sparked considerably interest in the scientific community [1]. The extraordinary transmission through these structures of subwavelength holes has been successfully explained in terms of the resonant tunneling of surface plasmon polaritons (SPP's)[2]. We have recently observed the enhanced transmission of terahertz radiation through gratings of subwavelength apertures; demonstrating this phenomenon at other wavelengths than optical [3]. Moreover our gratings are structured in silicon instead of metals. Due to free carriers available in doped semiconductors, they exhibit a behaviour at THz frequencies similar to the behaviour of metals at optical frequencies. We will also show that the characteristics of the SPP's propagation and the enhanced transmission can be easily tuned by controlling the number of free carriers. Because the inherent tuning capabilities of semiconductors they offer an interesting alternative to metals for the enhancement of the transmission at low frequencies.

12:30 **LUNCH**

# Thursday, May 27, 2004 Afternoon

## Session II: Surface plasmons 2
## Session chair: N.J. Halas (Rice University, Houston TX, USA)

**A2-II.1** 14:00 -Invited-

LINEAR AND NONLINEAR MULTIPLE SCATTERING OF SURFACE PLASMON POLARITONS AT NANOSTRUCTURED SURFACES

**Sergey I. Bozhevolnyi**, Department of Physics and Nanotechnology, Aalborg University, Pontoppidanstræde 103, 9220 Aalborg Øst, Denmark

Interference in multiple scattering of light in nanostructured media may bring about a number of fascinating phenomena, of which strong (Anderson) localization in random media and associated giant local field enhancement are probably the most prominent and intriguing ones. These phenomena can be realized and investigated by making use of surface plasmon polaritons (SPPs) that being (quasi-) two-dimensional interface waves allow one to relatively easy achieve the localization threshold and to employ scanning near-field optical microscopy (SNOM) for their studies. Using SNOM of random structures consisting of individual (~ 70-nm-high) gold bumps (and their clusters) with the density of 75 m-2 fabricated on a gold film surface, the phenomena of strong SPP localization and waveguiding along scattering-free channels are investigated in the wavelength range of 713 – 815 nm [1]. These structures were also used in the experiments with second-harmonic (SH) generation obtained with a tightly focused tuneable (750 – 830 nm) laser beam. The local field enhancement effect manifested itself in the form of resolution-limited bright SH spots whose positions were wavelength and polarization dependent [2]. The observed phenomena are discussed within the framework of multiple SPP scattering and possibilities for further investigations and applications of these effects are considered.

[1]S.I. Bozhevolnyi, V.S. Volkov, and K. Leosson, "Localization and waveguiding of surface plasmon polaritons in random nanostructures," Phys. Rev. Lett. 89, 186801 (2002).

[22]S.I. Bozhevolnyi, J. Beermann, and V. Coello, "Direct observation of localized second-harmonic enhancement in random metal nanostructures," Phys. Rev. Lett. 90, 197403 (2003).

**A2-II.2** 14:30

SURFACE-PLASMON ENHANCED EMISSION RATE AND EFFICIENCY OF SLOW OPTICAL EMITTERS

J. Kalkman and A. Polman, FOM-Institute AMOLF, Kruislaan 407, 1098 SJ Amsterdam, The Netherlands

Erbium ions, emitting at 1.5 micrometer, have radiative emission rates as low as 100 per second, due to the forbidden nature of their intra-4f transitions. As a result, Er-based LEDs have low output power, and the Er emission is very sensitive to non-radiative processes. We demonstrate how these problems may be relaxed by proper engineering of Er-doped microstructures that support surface plasmons (SPs).

Silica glass and silicon samples implanted with Er were covered with Ag films. The optically excited Er ions decay by near-field coupling to the metal, generating SPs. In the infrared, SP propagation lengths are beyond 100 micrometer, and the SP energy is coupled out into the far field through a grating fabricated using electron beam lithography. We observe a wavelength-dependent emission angle and polarization that is in good agreement with dispersion calculations for the Ag-silica system, taking into account the grating vector. We also present calculations of the distant-dependent dissipated power as a function of wave vector for an oscillating dipole above the silver/dielectric interface. We take into account the local optical density of states, direct coupling to excitonic states in the metal, and the generation of SPs, and have evaluated the relative contribution of each of these processes as a function of distance from the metal. Photoluminescence decay measurements show that for Er ions in glass, 120 nm away from the surface, presence of the metal increases the emission rate from 110 to 170 per second. The enhancement is the direct result of coupling to SPs. As the SP energy can be coupled out to the far field at near-unity efficiency, the overall emission rate and quantum efficiency are enhanced.

**A2-II.3** 14:45

OPTICAL TRANSMISSION OF ISOLATED SUBWAVELENGTH APERTURES IN REAL METALS

A. Degiron(a),H.J. Lezec(a),N. Yamamoto(b)and T.W. Ebbesen(a), (a)ISIS, Louis Pasteur University, 8,allée G. Monge, 67000 Strasbourg, France, (b)Physics Department, Tokyo Institute of Technology, 2-12-1 Oh-okayama, Meguro-ku, Tokyo 152-8551, Japan

The development of both near-field optical devices and new miniaturized photonic structures has brought subwavelength aperture into common use. Nevertheless, their optical properties are far from being well understood and it is generally admitted that they show poor transmittivity and strong diffraction. Here we report that light impinging on isolated subwavelength holes in metal films excite localized surface plasmon modes on the aperture ridge. Their activation gives rise to optical tunneling with unexpected enhanced transmission peaks and directionality. These properties follow from the dipolar nature of the LSP modes and can be tuned by an appropriate design of the aperture shape. These findings are of relevance for the current trends in subwavelength optics.

**A2-II.4** 15:00 -Invited-

METAL NANOPARTICLE PLASMON WAVEGUIDES FOR ELECTROMAGNETIC ENERGY TRANSPORT

**Stefan Alexander Maier**, Department of Applied Physics, California Institute of Technology, MC 128-95, Pasadena CA 91125, USA

The miniaturization of optical devices requires that light can be localized and guided in volumes on the order of or below the diffraction limit of light. Metal nanostructures such as wires and ordered nanoparticle arrays are a unique means for such light localization and will enable a new generation of subwavelength optical devices. Basic building blocks of such devices will be plasmon waveguides that guide light at visible and near-infrared frequencies due to coupled plasmon interactions.

One-dimensional arrays of Au and Ag particles with an interparticle spacing significantly smaller than the wavelength of light allow the guiding of electromagnetic energy at visible frequencies upon resonant excitation. Finite-difference time-domain simulations of energy propagation in these subwavelength plasmon waveguides will be presented. Local resonant excitation of the waveguides via apertured probes allows for the direct detection of energy transport over several hundred nanometers using fluorescent nanoparticles as detectors. Such devices could find useful applications as end-structures to more conventional waveguides for channeling energy to nanoscale detectors. Due to Ohmic resistive heating in the metal nanoparticles upon excitation, there exists a fundamental trade-off between a tight energy confinement to the nanoparticle structure and loss. For non-resonant excitation of Au nanoparticle plasmon waveguides at 1.5 micron, the absorptive losses are reduced by about 3 orders of magnitude, and a low radiative loss can still be achieved using a two-dimensional waveguide design with a lateral grade in particle size. Finite-difference time-domain simulations and initial experimental results on fiber probing of these waveguides will be presented.

15:30 **BREAK**

## Session III: Negative refraction, near-field effects
## Session chair: S.I. Bozhevolnyi (Aalborg University, Aalborg, Denmark)

**A2-III.1** 15:45

THE BLACK CORNER REFLECTOR

S. Guenneau(a), B. Gralak(b) J.B. Pendry(a), (a)The Blackett Laboratory, Imperial College London, Prince Consort Road, London SW7 2AZ, UK, (b)FOM-Institute for Atomic and Molecular Physics, Kruislaan 407, 1098 SJ Amsterdam, The Netherlands

Negative refractive index materials [1] have excited the optics community both through the intriguing possibilities they appear to offer, and the challenges they present to our understanding of the diffraction process. Most intriguing of all is the possibility of a lens whose resolution is limited not by wavelength, but only by the losses in the constituent materials. The resolution of this lens increases without limit as the losses tend to zero. The cornerstone of the perfect lens [2] is that a negatively refracting index slab (n = -1) is in some sense complementary to an equal thickness of vacuum and cancels out its presence [3]. Moreover, the compensating effect of the slab extends not only to radiative components of the field, but more importantly to the evanescent near field which conveys the
sub-wavelength of the image, due to the existence of surface plasmons (see [4] for similar features). Ordinary lenses do not capture this near field, hence the limitations to their resolution.

However the perfect lens is only one member of a whole category of systems, such as two orthogonal planes delimiting positive and negative index media, which satisfy a generalized lens theorem [3]. We shall see in this talk that good use of coordinate transformations tackles geometries related to one another by such mirror symmetry. The tool of choice will be a generalised transfer matrix formalism. Our approach amounts to solving the vector Maxwell system by taking full account of the invariance of a 1D Photonic Crystal (which consists of positive and negative refractive index layers) in, say, $x_1$ and $x_2$ (using a Fourier Transform), and its periodicity in $x_3$ (by means of Floquet-Bloch decomposition). We need only assume that the electromagnetic field satisfies a prerequisite energy criterion of square integrability. We achieve a clean mathematical derivation which leads to an analytical expression for the field by means of the transfer matrix formalism. Our meta-material requires of course some modifications with respect to the original algorithm [5]: we need now consider some loss in the layers with negative material (for causality reasons), and we also introduce an infinity of point current sources (vector model) radiating in the overall periodic structure.

The primary interest of our study lies in the apparent similarity between the 1D periodic case and the *Negative Corner reflector* via a coordinate transformation, as shown in [3]. We demonstrate the possibility to design a meta-material which traps states associated to a specific frequency, around infinitely circulating loops. As far as that frequency is concerned, this optical system is invisible to an observer. Hence, it is tempting to call it *The Black Corner reflector.* The electromagnetic field within this structure is unusually singular and, with time, grows to infinity almost everywhere in the limit of zero absorption. This may pave the way to photon storage for quantum cryptography or otherwise.

[1]R. Shelby, D.R. Smith, S. Schultz, “Experimental verification of a negative index of refraction”, Science, vol. 92, p. 297, 2001

[2]J.B. Pendry, “Negative refraction makes a perfect lens”, Phys. Rev. Lett., vol. 85, p. 3966, 2000

[3]J.B. Pendry, S.A. Ramakrishna, “Focusing light using negative refraction”, J. Phys. Cond. Matter, vol. 15, p. 6345, 2003

[4]L. Martin-Moreno, F.J. Garcia-Vidal, H.J. Lezec, K.M. Pellerin, T. Thio, J.B. Pendry and T.W. Ebbesen, “Theory of Extraordinary Optical Transmission through Subwavelength Hole Arrays”, Phys. Rev. Lett., vol. 86, p. 1114, 2001

[5]J.B. Pendry, “Photonic band structures”, Jour. Mod. Opt., vol 41, No. 2, p. 209-229, 1994

**A2-III.2** 16:00

REFLECTANCE CHARACTERIZATION OF OPALS OF CORE-SHELL AU/POLYSTYRENE

P.-T. Miclea, S.G. Romanov, C.M. Sotomayor Torres, Institute of Materials Science, University of Wuppertal, Gauss Str. 20, 42097 Wuppertal, Germany, A. Susha, Max Planck Institute of Colloids and Interfaces, 14424, Potsdam, Germany, Z. Liang, F. Caruso, Department of Chemical and Biomolecular Engineering, University of Melbourne, Australia

A robust and wide omidirectional photonic bandgap is expected to be open by using photonic crystals obtained form metallo-dielectric materials. In this report we present the experimental results of the angle-resolved reflectance measurements of the opal structures formed by the assembly of the polystyrene spheres covered with Au nanoparticles.

The surface plasmon resonance of Au nanoparticles changes in opals from the single peak to the set of peaks in correspondence to the shape of nanoparticles aggregates. The diffraction resonance in Au covered opals evolves away from the dielectric type behavior, when it overlaps the plasmon resonance. Increase the Au content up to ~50 wt.% results in broadening of resonances and emerging bands with usual angular dispersion. This behavior is explained by considering the changes of the real dielectric function of the bare opal in the complex dielectric function of the metal nanoparticles and the topology of the metallodielectric opals.

**A2-III.3** 16:15

OPTICAL PHASE EFFECTS AND RESONANCE SHIFT IN SCATTERING-TYPE NEAR-FIELD INFRARED MICROSCOPY

T. Taubner, F. Keilmann and R. Hillenbrand, Max-Planck-Institut für Biochemie, 82152 Martinsried, Germany

A scattering-type near-field optical microscope (s-SNOM) detects light scattered at the sharp tip of a probing needle and allows imaging with subwavelength resolution, independent of the wavelength used for illumination[1]. We now study amplitude and phase of light scattered from a s-SNOM's tip probing a flat SiC sample, at mid-infrared frequencies where surface phonon polaritons resonantly enhance the tip-sample near-field interaction [2]. A nanometer-scale variation of the gap width between tip and sample causes the optical phase to change dramatically and the resonance to shift. Both effects can be explained by theory that treats the system as a point dipole (tip) interacting with its image dipole (sample), in electrostatic approximation. The phase effects and resonance shifts are not restricted to phonon polariton excitation in polar dielectrics like SiC, but should be observable also for resonances related to plasmons and excitons.

[1] T. Taubner, R. Hillenbrand and F. Keilmann, Journal of Microscopy 210, 311 (2003)
[2] R. Hillenbrand, T. Taubner and F. Keilmann, Nature 418, 159 (2002)

**A2-III.4** 16:30

FLUORESCENCE TRANSMISSION THROUGH NANOSTRUCTURED METAL FILMS

Yongdong Liu and Steve Blair, University of Utah, Electrical and Computer Engineering Department, 50 S. Central Campus Drive, Rm 3280, Salt Lake City UT 84112, USA

We demonstrate the transmission of fluorescence through periodically modulated metal films. In one-dimensional corrugated films, transmission is mediated by coherent scattering of surface plasmons directly excited by fluorophores on the top surface of the film. This scattering is shown to be a two-dimensional problem in that diffraction orders along both axes are obtained with well-defined states of polarization. In films consisting of two-dimensional arrays of sub-wavelength apertures, an additional mechanism exists in the direct transmission of fluorescence through the apertures, which is the dominant mechanism of transmission as shown by measurement of the radiation pattern from these structures. In addition, the intensity of fluorescence from the apertures is greater than one would expect, due in part to the buildup of excitation light within the apertures.

**A2-III.5** 16:45

SPONTANEOUS DECAY DYNAMICS IN ATOMICALLY DOPED CARBON NANOTUBES

Igor Bondarev and Philippe Lambin, Laboratoire de Physique du Solide, Facultes Universitaires Notre-Dame de la Paix, 61 rue de Bruxelles, 5000 Namur, Belgium

We report a strictly non-exponential spontaneous decay dynamics of an excited two-level atom placed inside or at different distances outside a carbon nanotube (CN). This is the result of strong non-Markovian memory effects arising from the rapid variation of the photonic density of states with frequency near the CN. The system exhibits vacuum-field Rabi oscillations, a principal signature of a strong atom-vacuum-field coupling regime, when the atom is close enough to the nanotube surface and the atomic transition frequency is in the vicinity of the resonance of the photonic density of states. Caused by decreasing the atom-field coupling strength, the non-exponential decay dynamics gives place to the exponential one if the atom moves away from the CN surface. Thus, atom-field coupling and the character of the spontaneous decay dynamics, respectively, may be controlled by changing the distance between the atom and CN surface by means of a proper preparation of atomically doped CNs. This opens routes for new challenging applications of atomically doped CN systems in nanophotonics as various sources of coherent light emitted by dopant atoms. In other words, similar to semiconductor microcavities [1] and photonic band-gap [2] materials carbon nanotubes may qualitatively change the character of atom-electromagnetic-field interaction, yielding a strong atom-field coupling regime in certain cases. This opens routes for new challenging nanophotonics applications of atomically doped CN systems as various sources of coherent light emitted by dopant atoms.

[1] D.Dini, R.Koehler, A.Tredicucci, G.Biasiol, and L.Sorba, Phys. Rev. Lett. 90, 116401 (2003).
[2] M.Florescu and S.John, Phys. Rev. A 64, 033801 (2001).

17:00-19:00 POSTER SESSION

**A2/P.01** MANIPULATING OPTICAL PLASMON POLARITONS WITH SURFACE NANOSTRUCTURES

A.L. Stepanov, H. Ditlbacher, J.R. Krenn, A. Hohenau, A. Leitner, F. R. Aussenegg, Institute for Experimental Physics and Erwin Schrödinger Institute for Nanoscale Research, Karl-Franzens-University Graz, 8010 Graz, Austria

The present know-how and technology with regard to plasmon effects on the micro- and nanoscale seem sufficiently advanced to allow the development of functional surface plasmon polariton (SPP) based optical devices. Therefore, however, quantitative information describing SPP phenomena is required. In the former study metal nanostructures fabricated by electron-beam lithography on thin metal film performed as mirrors, beamsplitters, and interferometers was demonstrated by qualitative fluorescence imaging [1]. On the other hand, the qualitative measurement of light/SPP coupling was shown by analyzing of leakage radiation [2]. In the present work, we applied the measurement of leakage radiation to the excitation and propagation of SPPs in silver films with various surface nanostructures, thereby gaining quantitative information. We consider the interaction of SPPs with lithographically fabricated surface nanostructures, deducing detailed information about SPP reflection, transmission, and scattering. The factors, which influence SPP propagation in complex nanostructures are discussed.

[1] H. Ditlbacher, J.R. Krenn, G. Schider, A. Leitner, F.R. Aussenegg, Appl. Phys. Lett. 81, 1762 (2002). [2] H. Ditlbacher, J.R. Krenn, A. Hohenau, A. Leitner, F.R. Aussenegg, Appl. Phys. Lett. 83, 3665 (2003).

**A2/P.02** TRANSMISSION,REFLECTION AND ABSORPTION IN THE SUBWAVELENGTH HOLES ARRAYS

W.L. Barnes(a), W.A. Murray(a), J. Dintinger(b), E. Devaux(b), H.J. Lezec(b) and T.W. Ebbesen(b), (a)School of Physics,University of Exeter, Stocker Road, Exeter, U.K., (b)ISIS, Louis Pasteur University, 8 allée G. Monge, 67000 Strasbourg, France

Within the framework of the study of enhanced light transmission through subwavelength holes array, we investigate the fate of the light power in such structures. With this aim, we measured the dispersion curves, under different polarisation conditions, in both transmission and reflection. The results are consistent with the presence of resonant surface plamon modes in the structure, and they show that the transmittance maxima are associated with both reflectance minima and absorption maxima.

All these findings fit well with the model in which transmission is based on diffraction assisted by the enhanced fields associated with surface plasmons.

**A2/P.03** SURFACE PLASMONS IN METAL NANOPARTICLES ON FLAT AND PATTERNED SEMICONDUCTOR SURFACE

N.L. Dmitruk, T.R. Barlas, V.R. Romanyuk, Institute for Physics of Semiconductors of NASU, Pr. Nauki 41, 03028 Kyiv, Ukraine, I.N. Dmitruk, Kyiv National Taras Shevchenko University, Pr. Glushkov 6, 03127 Kyiv, Ukraine, and A. Szekeres, Institute of Solid State Physics, Sofia, Bulgaria

Island metal films on semiconductor patterned surface are some model nanophotonic structure for investigation of electromagnetic waves interaction with inhomogeneous solid surface, especially at surface plasmon excitations.

Gold nanoparticles were produced by photochemical deposition from aqueous solution of gold salt or vacuum evaporation on flat or patterned GaAs surfaces, performed by anisotropic chemical etching or holographic photochemical etching. We investigated nanostructures from isolated spheroidal nanoparticles of different sizes (5-25 nm) to chain-like structures, including percolation threshold. Statistical properties of metal clusters and pattern substrate were studied by SEM, AFM and EDS/X-ray microanalysis system. Electronic structure was investigated with several optical methods (angle-resolved reflection of polarized light, spectral ellipsometry) in the region 300 – 900 nm. Various effective-medium approximations were used to describe the experimental spectra. We observed splitting of plasmon resonance in the reflection spectra. For interpretation of reflection/absorption data new generalized microscopic theory of the electrostatic response of a system of metal spheres on a semiconductor surface was used. In the dipole approximation the influence of substrate on the polarizability of spheres was taken into account.

**A2/P.04** SURFACE PLASMON INTERACTION WITH SINGLE GROOVES IN THIN SILVER FILMS

J. Seidel, S. Grafström, L. M. Eng, Institut für Angewandte Photophysik, University of Technology Dresden, 01062 Dresden, Germany, L. Bischoff, FZ Rossendorf, Institut für Ionenstrahlphysik und Materialforschung, 01314 Dresden, Germany and T. Gemming, Leibniz-Institut für Festkörper- und Werkstofforschung Dresden e.V, 01069 Dresden, Germany

The propagation of surface plasmons in thin silver films and their interaction with defined surface grooves are presented. Of interest to photonic structures are both the optical transmission across barriers and other structures, but also the coupling to free-space electromagnetic waves. We present results on plasmon transmission and reflection at grooves written with a focused ion beam (FIB) into a thin silver film. In order to monitor the optical properties of travelling plasmons excited in attenuated total reflection (ATR), we apply near-field optical microscopy using a dielectric fiber tip. Our results agree well with former theoretical predictions. Furthermore, we report on optical observation of plasmons propagating at the silver-glass interface rather than the silver-air interface as usually monitored. This manifests itself in a very exciting beating phenomenon between plasmon modes running at the silver-air and silver-glass interface.

**A2/P.05** NEAR-FIELD INDUCED SURFACE PHONON POLARITONS ON FOCUSED ION BEAM IMPLANTED SiC

Nenad Ocelic, Rainer Hillenbrand, Nano-Photonics Group, Max-Planck Institute for Biochemistry, 82152 Martinsried, Germany

We used a home-built scattering-type (or apertureless) scanning near-field infrared microscope (s-SNIM) to study phonon polariton excitations on a SiC surface patterned by focused ion beam implantation. In our experiment the sharp probing tip of an atomic force microscope (AFM) is illuminated by infrared light from a CO2 laser and both the amplitude and phase of backscattered light are detected. Tuning the laser between 10.6um and 11.2um, we found phonon polariton resonance of the tip-sample near-field interaction[1] whose magnitude and spectral position strongly depend on the sample's local dielectric function. Since the dielectric function depends on the local crystal structure, we can differentiate between crystalline SiC and amorphous SiC regions produced by implantation, as well as the transition regions between them. Thus, our method could be used to map radiation damage caused by the ion implantation process. We also discuss the possibility to use focused ion beam patterning to fabricate ultra-durable, high density read-only memories or planar waveguide structures for nanoscale transport and manipulation of infrared radiation by surface phonon polaritons.

[1] R.Hillenbrand, T.Taubner, F.Keilmann, Nature, 418, 159-162 (2002)

**A2/P.06** SURFACE PLASMONS IN ANISOTROPIC AU-SHELL/SILICA-CORE COLLOIDS

J.J. Penninkhof(a), C. Graf(b,c), A. Moroz(b), A.Polman(a), A. van Blaaderen(b), (a)FOM Institute AMOLF, Amsterdam, The Netherlands, (b)Universiteit Utrecht, Utrecht, The Netherlands, (c)Universität Würzburg, Würzburg, Germany

Metallodielectric colloids form a new class of interesting building blocks for photonic applications. We present the fabrication of monodisperse silica cores with diameters in the range of 300 to 500 nm, covered with a 20 to 70 nm thick metal shell of Au or Ag. The colloids are synthesized by wet chemical processes involving Stöber growth (silica cores) and reduction of HAuCl4 onto small Au clusters attached to the silica by 3-amino-propyltrimethoxysilane. Some silica-core/Au-shell colloids were covered with an additional silica shell.

The optical properties of these colloids are governed by the plasmon resonances of the metal shell. In theory, a plasmon frequency can be shifted in energy from 2.3 eV to 0.1 eV by variation of the relative size of the core and the shell. The peak in optical extinction for our colloids is found in the visible, at 1.7 eV. For this spherical geometry the electromagnetic response obeys the classical Mie scattering theory quantitatively. We use ion beam irradiation (30 MeV Cu) to change the shape of Au-shell colloids from spherical to oblate ellipsoidal. The ion beam-induced plastic deformation is driven by anisotropic flow of the silica core, and is reduced when the metal shell thickness is increased. The non-spherical geometry of the particles gives rise to strong anisotropic characteristics in the plasmon resonances as probed by angle-resolved optical extinction, with an observed peak redshift as large as 0.8 eV. The results will be compared to calculations of angle-dependent scattering on ellipsoidal colloids.

**A2/P.07** TOTAL TRANSMISSION THROUGH SUBWAVELENGTH HOLE ARRAYS

M. Beruete(a), M. Sorolla(a), I. Campillo(b), J.S. Dolado(b), L. Martín-Moreno(c) and F.J. García-Vidal(d), (a)Departamento de Ingeniería Eléctrica y Electrónica, Universidad Pública de Navarra, 31006 Pamplona, Spain, (b)Labein Centro Tecnológico, Cuesta de Olabeaga, 16, 48013 Bilbao, Spain, (c)Departamento de Física de la Materia Condensada, ICMA-CSIC, Universidad de Zaragoza, 50015, Zaragoza, Spain, (d)Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, 28049 Madrid, Spain

By using subwavelength arrays of holes in metal films it has been demonstrated experimentally in the optical regime that transmisión can be greatly enhanced. A fully three-dimensional theoretical study of Extraordinary Optical Transmission (EOT) in arrays of holes has been demonstrated. It is now well established that the origin of this EOT is the excitation of surface electromagnetic modes of the periodic metal surface.

They reflect practically all the incident radiation with the exception of some selected pass bands in a complementary way as it happened in Electromagnetic Band Gap structures. Therefore, these periodic structures can be considered, in some sense, as a kind of Metamaterial. Before Ebbesen experiment, there were several experimental studies of transmission of light through arrays of holes in the far infrared, mid infrared and infrared ranges. In the microwave range, perforated plates were also studied since the sixties of last century. We present experimental measurements of total transmission through subwavelength hole arrays performed in the millimeter wave range from 45 to 110 GHz. The prototypes under test are perforated aluminum plates. The size of the array of 31 x 31 holes. We have used different samples in order to make a parametric study of the structure. The results presented show the phenomenon of enhanced transmission in subwavelength perforated metallic plates in the millimeter wave regime in good agreement with the theoretical model and numerical simulation results presented in the optical range. These results in the millimetre wave range open the possibility of a rich variety of potential applications as Frequency Selective Surfaces in these frequency ranges.

**A2/P.08** SELECTIVE TRANSMISSION THROUGH SUB-WAVELENGTH METALLIC SLITS, P.Quémerais, A. Barbara, J. Leperchec and T. López-Ríos, LEPES-CNRS, 25 av. des Martyrs, BP 166, 38042 Grenoble Cedex 9, France

One dimensional rectangular metallic gratings enable enhanced transmission of light for specific resonance frequencies. As was previously proved experimentally and theoretically[1], two kinds of mechanisms participate to enhanced transmission: (i) waveguides and (ii) surface plasmons polaritons (SPP). We have focused on the first kind (i) and show that due to the fundamental nature of these resonances, the transmission can be tremendously improved by an attenuated total reflection configuration[2].

[1]A. Barbara, P. Quémerais, E. Bustarret and T. López-Ríos, Phys. Rev. B **66**, 161403(R), 2002
[2]P. Quémerais, A. Barbara, J . Leperchec and T. López-Ríos, submitted

**A2/P.09** PHOTO-DETECTIVE PROPERTIES OF NANO-PATTERNED MODULATION-DOPED In0.48Al0.52As/In0.47Ga0.53AS GROWN ON THE SEMI-INSULATING Fe-DOPED InP SUBSTRATE

Hongjoo Song, Hong Goo Choi, Youngchang Jo, Hoon Kim, Korea Electronics Technology Institute, Korea

We fabricated the nano-patterned photoconductor using the modulation-doped In0.48Al0.52As/In0.47Ga0.53As grown on the semi-insulating Fe-doped InP substrate. Processing the E-beam lithography and ICP-RIE, we could produce the nano-patterns with the various width and length from the 60 nm to 300 nm, which were identified by FE-SEM. The photon-absorbing area was formed as single nano-channel and multi-nano-channel. To analyize the nano-device as photodetector, we characterized the responsivity, dark current and temperature-dependent photosensivity for the detective wavelength range, in detail.

**A2/P.10** WAVEGUIDING EFFECTS IN LAYER BY LAYER DEPOSITED FILMS OF CHEMICALLY SYNTHESIZED CdTe NANOCRYSTALS

W. Heiss, J. Roither, K. Hingerl, S. Andreeva, Institute of Semiconductor and Solid State Physics, University of Linz, Altenbergerstraße 69, 4040 Linz, Austria, M. Kovalenko, P. Feichuk, O. Panchuk, Institute of Inorganic Chemistry, University of Chernivtsi, Chernivtsi 58012, Ukraine

Since chemically synthesized nanocrystals (c-NCs) give high photoluminescence quantum efficiencies they are very promising for the development of novel light emitting devices and lasers. So far, stimulated emission from c-NCs has been achieved by pulsed optical excitation only, and not in cw operation mode. To obtain this, the currently used laser structures have to be considerably improved. For high gain, the c-NCs have to be closely packed and for lateral emitting laser devices the radiation of the c-NCs has to be coupled efficiently to optical wave-guides which can form the laser resonator. Therefore, in this work we investigate different structures, in which optical wave-guides for NC emission are provided either by (a) the NC film itself, (b) a dielectric thin layer, or (c) the substrate. To obtain closely packed c-NC films, CdTe NCs were deposited in form of bilayers (BLs) by static adsorption using oppositely charged polycations. The wave-guiding was investigated by photoluminescence experiments, detected in lateral direction via the edge of the sample as a function of the distance between the exciting laser spot and the point of detection. The best results are obtained, when the NC film itself acts as wave-guide, in spite of the fact that the used 160 nm thick film allows only to accommodate one optical mode within the c-NC film.

**A2/P.11** APPLICATION OF THE BAND STRUCTURE ANALYSIS AND DYNAMICAL DIFFRACTION THEORY TO THE DESIGN OF VAPOUR SENSORS BASED ON POROUS SILICON MICROCAVITIES

L. De Stefano(a), V. Mocella(a), L. Moretti(b), I. Rendina(a), (a)Institute for Microelectronics and Microsystems, CNR Sez. Napoli, Via P. Castellino 111, 80131 Napoli, Italy, (b)DIMET University of Reggio Calabria, Loc. Feo di Vito, 89060 Reggio Calabria, Italy

Two different original theoretical approach for the analysis of a vapour sensors based on a porous silicon optical microcavities are presented. The devices under analysis are based on a cavity with a high porosity layer of optical thickness B/2, where B is the Bragg resonant wavelength, enclosed between two distributed Bragg reflectors with seven periods made of alternate low and high porosity layers. When such a porous silicon microcavity is exposed to chemical vapours, a marked red-shift of its resonant peak, ascribed to capillary condensation of vapour in the pores, is observed. According to the first approach, the features of porous silicon microcavities are analyzed looking at the correspondent band structure. In particular, the microcavity structure is viewed as a 1-D photonic crystal with a defect of optical thickness B/2 giving rise to a narrow resonant transmittance peak at B in a wide transmittivity stop-band. We then compare the derivation of the band structure with an original approach based on the Dynamical Diffraction Theory (DDT), the same widely used in x-ray diffraction. The electron propagation and electromagnetic wave diffraction in periodic solids, respectively developed into band-theory and based on DDT, are formally identical. It appears therefore natural to perform an analysis of the features of an electromagnetic phenomenon, as the Photonic Band Gap, in analogy to the most direct antecedent electromagnetic theory, the DDT, which historically has also represented the direct reference for the derivation of the band-theory of electrons.

**A2/P.12** PHOTOLUMINESCENCE STUDIES OF ZINC SELENIDE QUANTUM DOTS

V.V. Nikesh(a), Hiroshi Ono(b), Shinji Nozaki(b), Shailaja Mahamuni(a), (a)Department of Physics, University of Pune, Pune 411 007, India, (b)Department of Electronic Engineering, The University of Electro-Communications, 1-5-1 Chofugaoka, Chofu-shi, Tokyo 182-8585, Japan

Quantum confinement in semiconductors leads to discrete transitions that are blue shifted in energy from the bulk [1]. Inhomogeneous broadening of the optical spectra due to size distribution and shape variations of the nanoparticles, conceal the fine structure in the energy states of quantum dots.

ZnSe nanoparticles of different sizes were synthesized by high temperature chemical route. Cubic zinc blende crystallites with sizes ranging from 2.5 nm to 4.5 nm showing only band gap luminescence were obtained. Low temperature photoluminescence excitation (PLE) measurements are carried out. The PLE spectra were fitted with Gaussians to determine the exact energies of higher excited states. This is the first report giving the details of electron energy levels of ZnSe nanoparticles. Here, we estimate the size of the ZnSe nanoparticles from tight binding calculations [2]. Though TEM can measure the size of the particles accurately, the samples that are studied have finite size distribution. Whereas features observed in PLE spectra give a more precise value of the transition energy of the first excited state from which the size of the ZnSe nanoparticles can be estimated using the tight binding calculations. The experimentally observed excited state transitions for ZnSe nanoparticles were compared with the reported EMA calculations [3]. The calculated values do not match to that obtained by PLE. Valence band mixing may be much more complicated than that can be handled by EMA formulations. The results are discussed in detail.

[1] U. Woggon, Optical Properties of Semiconductor Quantum Dots, Springer Verlag, Berlin (1997)
[2] S. Sapra and D. D. Sarma, Phys. Rev. B (2004)
[3] J.-B. Xia, Phys. Rev. B 40, 8500 (1989)

**A2/P.13** PHOTOLUMINESCENCE PROPERTIES OF SELENIUM TREATED POROUS SILICON

R. Jarimavicilta-Žvalioniena(a), V. Grigalilnas(b), R. Tomašilnas(c), I. Mikulskas(c), S. Tamulevicius(a,b), M. Andrulevicius(b), Š. Meškinis(b), (a)Physics department, Kaunas University of Technology, Studentu 50, 3031 Kaunas, Lithuania, (b)Institute of Physical Electronics, Kaunas University of Technology, Savanoriu 271, 3009 Kaunas, Lithuania, (c)Institute of Materials Science and Applied Research, Vilnius University, Saulatekio 10, 2040 Vilnius, Lithuania

Recently, porous silicon (PS), as a promising material for visible light emission by photoluminescence (PL) attracted attention due to possible photonic applications in different devices like LED, waveguide, field emitter, optical memory etc. Theoretical assumption basis on quantum explanation of the visible light luminescence, but the details of the mechanism are still not completely understood. In other hand, from the practical viewpoint, stability and lifetime of photoluminescence is very important factor. Stability and lifetime of PS photoluminescence can be significantly improved in the way of application of the efficient surface passivation method. Recently different chalcogenide (selenium or sulfur) treatments received attention as an alternative heteroepitaxy-compatible Si surface passivation method. In present study PS surface selenium treatment has been performed in order to improve stability and lifetime of PS photoluminescence.

PS layers were prepared at room temperature by electrochemical etching in HF:H2O:C2H5OH solution at working current of the etching process from 50 to 200 mA and the anodization voltage from 1 to 3 V. The back side of the sample was illuminated with a 50 W halogen lamp. Selenium treatment was performed by silicon immersion into the selenious acid aqueos solution. PL properties of initial and selenium treated PS structures were investigated in the visible and near-infrared spectral region. Silicon surface structural changes after selenium treatment were investigated by XPS. The influence of surface structural and composition changes on PL properties was defined.

**A2/P.14** MICROSCOPIC CHARACTERIZATION OF LUMINESCENCE OF ZnO NANOWIRES GROWN ON SAPPHIRE

F. Bertram, D. Forster and J. Christen, Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany, H. Fan, M. Zacharias and U. Gösele Max-Planck-Institute of Microstructure Physics Halle, Germany

Single crystalline ZnO nanowires have been synthesized from vapor phase in a horizontal resistance tube furnace. A mixture of ZnO and graphite powder was used as source material. The substrate was a-plane sapphire coated with a thin Au film (~3 nm). During the growth a rough ZnO seed layer is deposited on the sapphire. The ZnO nanowires stick out from the seed layer surrounded by island. The so grown nanowires exhibit an almost uniform shape (length ~2µm) with a hexagonal base plane (diameter ~80- 110nm) and a wire axis in c-direction. The density of the rods slightly varies over the sample surface (about 3x104cm-2). A direct correlation of structural and optical properties of the ZnO nanowires has been achieved on a microscopic scale using highly spatially and spectrally resolved cathodoluminescence (CL). The laterally integrated CL spectrum of an ensemble of wires exhibits broad donor bound exciton emission (FWHM = 3.5meV) dominated by I8. In addition, two spectral lines from deeply bound excitons (DBE) at lower energies are observed. Monochromatic CL images evidence the nanowires as source of the excitonic I8 emission. The strongly localized DBE luminescence originates from the seed layer. The CL characteristic of a single nanowire will also be presented.

**A2/P.15** THE NEW METHOD OF SI NANOWIRES GROWTH BY MW PLASMA ENHANCED CVD METHOD

N.N. Dzbanovsky, V.V. Dvorkin, A.F. Pal, V.G. Pirogov and N.V. Suetin Moscow State University, Institute of Nuclear Physics, Moscow, Russia

Silicon nanowires (SiNWs) are the promising candidate for nanoelectronics and Si-based photoelectronic devices. Laser ablation, thermal evaporation and CVD from silanes have been successfully used to synthesize SiNWs. New and more safe modification of MW Plasma Enhanced CVD process was developed using solid state Si target.The Si whiskers were grown by MWCVD method in H2 plasma at pressure of about 150 Torr and substrate temperature 1100-1200 °C, measured by Williamson Pro-S pyrometer. The Si(111) wafer covered by 20 nm Au layer was used as a substrate. The Si growing material was produced by evaporation of solid Si 400 mm thick plate, placed above the wafer at a distance of about 1 mm and heated over 1000 °C by MW plasma. So deposited SiNWs were studied by SEM, Raman and PL spectroscopy.

Diameter of deposited Si wires can vary from few nanometers to microns by changing of Au layer thickness and deposition parameters (MW power, hydrogen pressure and gas flow rates). PL spectra were measured both as just grown samples and after their oxidation. PL bands with peaks in the range of 541-726 nm were observed. Correlation between PL emission spectrum and SiNWs properties was studied.

Financial support from ISTC Projects # 2484 and # 2559 are acknowledged.

**A2/P.16** ELECTROOPTIC EFFECTS IN HYBRID POLYMER-SiC NANOCRYSTALS COMPOSITES

J. Boucle, A. Kassiba, M. Makowska-Janusik, I.V. Kityk and N. Herlin-Bolme

**A2/P.17** SUB-WAVELENGTH PATTERNING OF THE OPTICAL NEAR-FIELD

Romain Quidant and Gonçal Badenes, ICFO- Institut de Ciències Fotòniques, c/ Jordi Girona 29, 08034 Barcelona, Spain, Jean-Claude Weeber, LPUB, UMR-CNRS 5027, Optique submicronique, 9 av. Alain Savary, 21078 Dijon, France, Christian Girard, CEMES, UPR-CNRS 8011, 29 rue Jeanne Marvig, 31055 Toulouse, France

In the ongoing general trend for miniaturization, optics has shown much more difficulties than electronics to reach the nanometric regime. A main reason for this delay is the physical limit imposed by diffraction when focussing light. Indeed, the smallest diameter of an optical beam propagating in a dielectric medium of refraction index n is of the order of lambda = lambda_0/n , lambda_0 being the wavelength in free space. Confining light from a 3D laser beam (with its three k vector components real) down to subwavelength sizes imposes a reduction on its dimensionality.

In this paper we investigate a surface structure that can locally enhance optical potential gradients. Such potential gradients might offer the opportunity of optically confining nanosystems close to surfaces in relatively deep traps and controlling their transport through them. We report on the non-diffraction limiting patterning of the optical near-field by illuminating under total internal reflection a surface textured with a regular array of resonant gold nano-particles. Under appropriate conditions, the in-plane coupling between the Localized Surface Plasmons (LSP) fields gives rise to sub-wavelength light spots between the structures. Measurements performed with an Apertureless Scanning Optical Microscope (ASNOM) show good agreement with theorical predictions based on the Green dyadic method. This concept might offer a convenient way to elaborate extended optical trap landscapes for optical manipulation of submicrometre systems.

**A2/P.18** FABRICATION OF NEARFIELD PROBE UNDER THE INFLUENCE OF ELECTRON BEAM EXPOSURE

D.W. Kim, S.S. Choi, Department of Physics and Nanoscience, SunMoon University, Ahsan, Chungnam 336-708, Korea, J.S. Moon, J.H. Boo, Department of Chemistry, Sungkuynkwan University , Kyung Gi Do, Suwon 440-746, Korea

Recently there have been tremendous interests about near field optical lithographic techniques for the next generation gigabyte information storage devices. The near field optical lithographic technique will circumvent the classical diffraction limit and can provide the sub-wavelength size patterns less than 100 nm and the parallel data processing has been examined. Therefore, several parallel processing techniques such as multi-cantilever array and the nano-size aperture array have been previously reported. In this work, the nano-fabrication technique for the sub-wavelength size aperture array is presented. Initially, the (50´50) dot array was patterned on the SiO2 thermally grown on Si (100) substrate. Each dot has (5´5) mm2 pattern size. The anisotropic TMAH etching of the Si substrate was performed and followed by anisotropic stress-dependent thermal oxidation at 1000 °C and backside Si etching using TMAH solution. The opening of the nano-size aperture on the oxide pyramid array was carried out using water-diluted (50:1) HF solution. The uniformity of the (50´50) nano-size aperture array was examined carefully on the four corners of the array patterns. The average diameter of the aperture was ~260 nm and its deviation was found to be ~10%. The opening rate of the nano-oxide aperture presented the slightly higher that the expected data. The increased opening rate was attributed to the large amount of electron accumulation during FE-SEM measurements. The increased opening rate can be attributed to the Fermi level shift from electron accumulation on the nanoscale aperture area

**A2/P.19** SPONTANEOUS EMISSION IN A ONE-DIMENSIONAL PHOTONIC CRYSTAL

Adan S. Sanchez and P. Halevi, Instituto Nacional de Astrofisica, Optica y Electronica, Apdo. Post. 51, 72000 Puebla Pue, Mexico

We calculated the spontaneous emission by an atom immersed in a one-dimensional photonic crystal (PC) or superlattice (SL). The SL is assumed to be monolithic and the atom, represented by a classical dipole, is situated at an arbitrary distance from a dielectric surface. The emitted radiation is allowed to propagate in any direction; thus we apply Fermi's Golden Rule to both TE and TM modes. We find that the emission rate into both polarizations exhibits a remarkable signature of the photonic band structure; this is especially true for the TE modes where emission can be completely suppressed. This behavior can be understood as the result of INTERNAL omnidirectional reflection - which is more difficult to achieve for the TM modes because of the Brewster effect. The light is emitted in part into radiative, and in part into evanescent modes. The latter correspond to resonant excitation of coupled waves guided by the dielectric layers. This resonance is very strong if the atom is close to the surface, in which case almost all of the light is emitted into evanescent modes. We find that the rate of emission can be as much as six times greater than in free space. We also calculated the power radiated by a gas of atoms that occupies the space between two dielectric layers. The present work is a generalization of our previous studies of spontaneous emission in a "Dirac-comb" SL; see Zurita-Sanchez, Halevi, and Sanchez, Phys.Rev.E 66, 046613(2002) and references therein.

**A2/P.20** ELECTRICAL TUNING OF PHOTONIC CRYSTALS INFILLED WITH LIQUID CRYSTALS

J.A. Reyes-Cervantes, Instituto de Física Universidad Nacional Autónoma de México, P. Halevi and J.A. Reyes-Avendano, Instituto Nacional de Astrofísica Optica y Electrónica, México

Our calculation concerns two-dimensional photonic crystals (PCs) of hollow cylinders (in a dielectric matrix) that are infilled with a nematic liquid crystal (NLC). A static electric field, applied parallel to the cylinders, tunes the optical response of the PC. A crucial aspect is the calculation of the dielectric tensor of the NLC. Here we generalize a preliminary study [1], now considering three possible configurations: escaped radial, planar radial, and axial. Further, the anchoring of the molecules at the cylinder walls now has an arbitrary strength. Finally, we address the full problem of inhomogeniety and anisotropy ot the NLC cylinders. We expect that such realistic modelling will give rise to phase transitions of the NLC as the electric field is varied, with strong impact on the photonic band structure.

[1] P.Halevi, J.H.Arroyo-Nunez, and J.A.Reyes-Cervantes, Proc.SPIE 5000,224(2003).

**A2/P.21** BLUE LUMINESCENT Alq3 SINGLE MOLECULES

M. Levichkova, J. Assa, H. Fröb, K. Leo, Institut für Angewandte Photophysik, Technische Universität Dresden, 01069 Dresden, Germany

Thin films of aluminum tris(8-hydroxyquinolinate) (Alq3) embedded in SiO2 matrix at dye concentrations corresponding to single-molecule distribution prepared by high vacuum co-evaporation are investigated. The optical and structural properties of the films are studied by luminescence and vibrational spectroscopy. It is shown that the dilution of the dye in the matrix leads to pronounced blue shift of the fluorescence maximum under UV excitation compared to pure Alq3 layers. This behavior is attributed to modified environment of the dye molecules by the matrix particles and possibly thermal effects as a result of their high kinetic energy. On the basis of the spectral data the formation of the recently reported but only in the new crystalline delta-phase obtained facial isomer of Alq3 during film growth is discussed. Furthermore, it is demonstrated that the variation of the preparation conditions is an effective way to obtain mixed layers with increased contribution of blue toward green luminescence of Alq3.

**A2/P.22** NEAR-FIELD PROBING OF MODE COUPLING AND RESONANCE DYNAMICS IN PHOTONIC BAND GAP MATERIAL

B. Cluzel, E. Picard, T. Charvolin, V. Calvo, E. Hadji, Laboratoire Silicium Nanoélectronique Photonique et Structure, Service de Physique des Matériaux et Microstructures, Département de Recherche Fondamentale sur la Matière Condensée, Commissariat à l'Energie Atomique, D. Gérard, F. de Fornel, Groupe optique de champ proche, Laboratoire de Physique de l'Université de Bourgogne, Unité mixte de Recherche Centre National de la Recherche scientifique, France

Up to now, the experimental way of characterization for photonic crystal based devices, like transmittance or photoluminescence measurements, lead to macroscopic information on their optical properties. Recent works have demonstrated the potential of near-field methods to collect information about the distribution of the electromagnetic field inside integrated devices. In this work, we have combined at the same time these two techniques to perform spectrally resolved near optical field imaging of photonic band gap structures like waveguides and integrated resonant cavities. We have first perform transmittance measurements on a broad spectral range to determine the spectral properties of the devices. Then near-field analysis by using a scanning near-field optical microscope(SNOM) in collection mode allow us to map the distribution of the electromagnetic field inside the devices as a function of the wavelength. By this way, we have evidenced the spectral dynamic of cavity mode establishment for a waveguide integrated photonic crystal. We also demonstrate coupling between Bloch modes having different parity in W1 photonic crystal waveguide. Finally, devices out-of-plane losses have been studied.

**A2/P.23** OPTICALLY VARIABLE IMAGING USING NANOIMPRINT TECHNIQUE

V. Grigaliunas, D. Jucius, S. Tamulevicius, A. Guobiena, V. Kopustinskas, Institute of Physical Electronics, Kaunas University of Technology, Savanoriu 271, 3009 Kaunas, Lithuania

Nanoimprint lithography becomes alternative technology for generation of patterns in nanometer range. We can refer to the nanoscale silicon transistor, nanoscale metal–semiconductor–metal photodetectors, fabricated using nanoimprint lithography. Nanoimprint technique was applied for the patterning of the organic light-emitting structures with a submicron resolution, Fresnel zone plates with a 75 nm minimum feature size and circular gratings with a 20 nm minimum linewidth, quantum point contacts etc.

In this work we demonstrate possible application of the nanoimprint technique for the generation of the optically variable diffractive images instead of well-known technologies, like dot-matrix mastering, photo-mask interference, electron beam lithography or classical holography. Nanoimprint technique for the generation of optically variable diffractive images is based on direct imprint with a set of a polished stamps in combination with reactive ion etching. Optically variable diffractive images and fidelity of the grating shape transfer were investigated by atomic force and scanning electron microscopes.

**A2/P.24** EBV-DEPOSITED SESQUIOXIDE FILMS ON ALPHA-AL2O3

Lutz Rabisch, Sebastian Bär, Günter Huber, Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

alpha-Al2O3 is an approved material in optical technology. Efficient laser operation in rare-earth doped Y2O3 bulk material has been demonstrated. Layer systems of both materials combine the properties and may have a multitude of possible applications, e.g. active and passive waveguides and crystalline coatings.

We report on the growth of trivalent Eu doped Y2O3- and (Lu/Sc)2O3 thin films (2 nm – 500 nm) on alpha-Al2O3 by electron beam evaporation EBV. The lattice mismatch between Y2O3 and alpha-Al2O3 is 4.7%. (Lu0.46/Sc0.54)2O3 has crystalline and optical properties very similar to Y2O3 but shows perfect lattice matching. The crystal structure of the films has been analysed by XRD and Surface XRD. The measurements reveal polycrystalline growth of the Y2O3 films on an initially amorphous interfacial layer. The growth temperatures of less then 400 °C and the low kinetic energy associated with the EBV process prevent epitaxial growth. In contrast, the (Lu/Sc)2O3 films show polycrystalline growth with an obvious epitaxial texture. Emission spectra of the 4f-4f transitions of the trivalent Eu ions show that the local symmetry of the Eu3p centres within the (Lu/Sc)2O3 films is identical to (Lu/Sc)2O3 bulk material. The Y2O3 films have slightly modified spectra compared to the bulk material. This effect originates in the polycrystalline structure of the films. The spectra of films thinner than roughly 10 nm show broadened emission lines. This effect increases with decreasing film thickness. In contrast, the fluorescence of a very thin (3 nm) Eu:Y2O3 film buried under an Al2O3 coating layer is identical to the bulk spectrum. This shows that the line broadening is due to changes of the local symmetry of the Eu3p centres at the film-air interfaces.

**A2/P.25** TAILORING GAP POROSITY THROUGH PHOTON ASSISTED ELECTROCHEMICAL ETCHING.

P.C. Ricci, A. Anedda, C.M. Carbonaro, F. Clemente and R. Corpino, Dipartimento di Fisica, Università di Cagliari and INFM UdR Cagliari, Cittadella Universitaria, 09042 Monserrato(Ca), Italy

Tailoring semiconductors porosity is a powerful tool to engineer the material properties, in terms of band gap, phonon spectrum, refractive index, resistivity and so on. Moreover, owing to its peculiar porous structure, GaP has recently enjoyed increasing attention and its highly isotropic random network has been called for an ideal candidate to study light localization.

In this work we study how the GaP porosity can be tuned by light irradiation during electrochemical etching process, Anodic etching of single crystalline n-type GaP was performed in H2SO4 0.5 M aqueous solution both under dark conditions and shining the samples with the 363.8 nm line of an Argon ion laser. By comparing the current voltage characteristics curves and the Raman spectra of samples obtained in different conditions we show that the formation mechanism of the porous layer is promoted by photons with an energy ³ GaP energy bandgap. A quantitative estimate of the porosity is given by the study of the Frohlich-type surface related vibrations by micro-Raman spectroscopy

**A2/P.26** REFRACTIVE INDEX ENGINEERING OF NANOPARTICLE-POLYMER COMPOSITES

Yigal D. Blum and D. Brent MacQueen, SRI International, Chemical Science and Technology Lab, Menlo Park CA, USA, Nobuyuki Kambe, NanoGram Corporation, San Jose CA, USA

Highly homogeneous nanoparticle-polymer composite materials are being developed for the next generation of photonic materials. These composites are of interest for engineering the refractive index of polymeric materials by applying chemistry suitable for the formation of photonic materials with self-assembled or periodical structures. Index engineering can be achieved by controlling loading fraction of nanoparticles with high refractive index (such as TiO2) within an organic host material. The technical challenge here for microphotonic device applications is to maintain a reasonable level of transparency while increasing the loading fraction of nanoparticles. The size of the particles, the elimination of agglomerations and the uniformity of their distribution within the polymeric phase are critical to minimize light scattering, particularly in the visible and infrared regions.

LASER-driven nanoparticle synthesis tools developed by NanoGram are used to generate a versatile range of self-standing nanoparticles that possess very narrow size distribution and no hard agglomeration. These nano-particles are blended at various loading levels, to at least 50 wt% in various polymeric matrices. The homogeneity of the nano-composite is achieved by surface modification of the nanoparticles. In addition to homogeneous blending and transparency or translucent behavior, some selective attraction of nanoparticles to polymer sites is also found. Optical characterization results such as optical absorption and index of these photonic nanocomposites will be discussed.

**A2/P.27** EXCITED STATE TPA OF SOLUBLE CARBON NANOTUBES AND TMTTF RADICAL DIMERS

Moreno Meneghetti(a), Mattia Garbin(a), Nicola Schiccheri(a), Gabriele Marcolongo(a), Maurizio Prato(b) Enzo Menna(a) and Michele Maggini(a), (a)University of Padova, Department of Chemical Sciences, 1 Via Marzolo, 35131 Padova, Italy, (b)University of Trieste, Department of Pharmaceutical Sciences,1 Piazzale Europa, 34127 Trieste, Italy

Two photon absorption (TPA) is a multiphoton property of molecules which is of great interest for many applications both in the material as well as bio-sciences. The dynamic of the excited states is very important for such applications. With longer pulses it is very probable to populate excited states from which further excitations can be obtained. In these cases the response of the material is very large due to the large polarizabilities of the excited states.

Here we will report our studies of soluble carbon nanotubes and of radical clusters by using long pulses (10 ns) from a Nd:YAG laser. Soluble carbon nanotubes have been obtained by different methods and allows one to obtain very stable solutions also under laser irradiation. We have found that solutions of these nanotubes show, both at the fundamental and at the first harmonic of the Nd:YAG, a multiphoton absorption behaviour which can be interpreted with a model based on an excited state two photon absorption with very large TPA cross sections. We will also report our studies of molecules which show large polarisation also in the ground state like stable radicals. In particular we have studied radicals of tetramethyltetrathiafulvalene (TMTTF) molecules which forms stable dimers in solution with a charge transfer excitation which absorbs in the near infrared spectral region. Also in this case we have found that a TPA from excited state model is appropriate for understanding the experimental data. These results are very interesting in view of the possibilities of obtaining very large cross section for multiphoton absorption processes which is one of the aims in the field of materials with multiphoton absorption properties.

**A2/P.28** PREPARATION, OPTICAL PROPERTIES AND UPCONVERSION EFFECT OF THE Y2O3 NANOPHOSPHORS DOPED WITH RARE EARTH IONS Er, Yb

Nguyen Vu(a), Tran Kim Anh(a), Man Hoai Nam(a), Charles Barthou(b) and Le Quoc Minh(a), (a)Institute of Materials Science, NCNST of Vietnam, 18 Hoang Quoc Viet Road, Nghia Do, Cau Giay, Hanoi, Vietnam, (b)Laboratoire d'Optique des Solids UMR 7601, Univ. P&M Curie,4 Place Jussieu, 75252 Paris, France

This work focuses on preparation, optical properties and up-conversion effect of Y2O3 nanophosphors doped with rare earth ions Er, Yb. Nanophosphors containing rare earth ions for luminescent application such as FEDs offer advantages with respect to potentially higher display resolution, longer lifetime, better mechanical integrity, better thermal management and better contrast in the visible and infrared range. The Y2O3 nanophosphors containing rare earth ions Er and Er,Yb were prepared via the combustion method using urea as a fuel. The particle size are 10 nm to 80 nm depending the technology conditions and were estimated by high resolution TEM. The luminescent spectra of Y2O3: Er and Y2O3: Er,Yb nanophosphors in the range of 1.53 micrometer [4I13/2 - 4I15/2], the red [4F9/2 - 4I15/2] and the green [2H11/2, 4S3/2 - 4I15/2] of Er3+ were detail studied. The up-conversion effect were investigated in the Y2O3 doped Er as well as codoped Yb, Er. The concentration dependence was investigated as a function of Er concentration (1, 2.5, 5, 7.5, 10, 15 mol %) and Er/Yb mole ratio of 1/5, 1/4, 2/3 in the case rare earth ion concentration 5 and 10 mol%. The up-conversion mechanisms were investigated. It was observed that luminescent efficiency of nanophosphors could be remarkably improved. The reduction in size of the nano-crystals can also involve an increase in the specific surface of the powder and thus a total increase in the intensity of luminescence due to a greater absorption. The application potential for two photon imaging, photonics and telecommunication will be discussed.

**A2/P.29** DIFFERENTIAL REFLECTIVITY OF A NANOSCALE SI-LAYERED SYSTEM

Z.T. Kuznicki and V. Svrcek, Laboratoire de Physique et Applications des Semi-conducteurs PHASE, CNRS UPR 292, 23 rue du Loess, 67037 Strasbourg cedex 2, France and M. Ley, University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland, B. Rousset, F. Rossel and G. Sarrabayrouse, LAAS-CNRS, 7 Avenue du colonel Roche, 31077 Toulouse cedex 04, France

The reflectivity of a multiinterface device containing a nanoscale Si-layered system [1] depends on the incident wavelength in a different way as that of corresponding test devices of the same design. The main difference between investigated and test devices concerns the presence or not of a carrier collection limit which blocks photogenerated carriers in their movement perpendicular to the surface. A 75 nm thick Si3N4 antireflection coating covers both c-Si layers, with (investigated) and without (test) a carrier collection limit. The collection limit is placed at 100-150 nm from the surface, at the point of the valence band offset (appearing at the c-Si/a-Si interface). The nanoscale Si-layered system has been formed by ion beam implantation and adequate thermal treatment.

The surface zone of investigated devices forms a free carrier reservoir having the form of a two-dimensional system (delimited by the Si surface and a buried plane). Under incident light, the reservoir contains a metallic carrier density, so corresponding optical features are dominated by the surface population. In this way, the design allows a modification of electromagnetic fields at the quasi-metallodielectric interface. The differential reflectivity shows four characteristic ranges: two with positive values (1.17 – 2.2 eV and 3.3 – 4.9 eV) and two with negatives values (2.2 – 3.3 eV and 4.9 – 6.1 eV). They could be related to different light-carrier coupling modes. [1] Z.T. Kuznicki, Applied Physic Letters, 81(2002)4853

**A2/P.30** SELENIUM/ZEOLITE NANOCOMPOSITES

Andreas Goldbach and Marie-Louise Saboungi, Centre de Recherche sur la Matière Divisée, 1b rue de la Férollerie, 45071 Orléans, France

Confinement of materials in molecular sieves is a straightforward method to imprint a nanostructured architecture on them. We carried out extensive studies on nanocomposites of selenium in zeolites, because seleniumn is an important technical semiconductor, and the interaction between the ionic matrices and the semiconductor provides intriguing possibilities for tuning the band gap of the semiconductor. In particular we studied the effects of zeolitic counter-cations on the structure, electronic properties, and thermodynamic and reactive stabilities of seleniumencapsulated in zeolites Y and A. The selenium structure can be precisely controlled by appropriate selection of the zeolite counter-cation, allowing a continuous transition from essentially chain- to solely ring-containing composites. Competition experiments disclosed that the selenium inside the nanopores is stabilized through bonding to the zeolitic cations and also through cyclization. The low-frequency Raman spectra yielded the first insight into the intrinsic length scale of the selenium dynamics in chain-type nanocomposites, and indicated that the microscopic dynamics of ring-type nanocomposites are markedly different. The selenium band gap broadens from the bulk value of 2 eV up to 3 eV in confinement but it can be narrowed again through interaction with transition metal counter-cations. Thus, the band gap of the confined semicondutor can be tailored within the whole optical range. Also, the photo-stability of the nanocomposites depends on the selenium structure. The photodecomposition is a delicate function of the counter-cation and highly selective, yielding charged and neutral degradation products of differing composition.

# Friday, May 28, 2004 Morning

## Session IV: Surface plasmons 3
## Session chair: J. Krenn (Karl-Franzens-University, Graz, Austria)

**A2-IV.1** 08:30 -Invited-

TRANSMISSION OF LIGHT THROUGH SUBWAVELENGTH APERTURES

**L. Martin-Moreno**, Universidad de Zaragoza, Spain and F.J. Garcia-Vidal, Universidad Autonoma de Madrid, Spain

In this talk we address from a theoretical point of view two physical phenomena that are related to the excitation of surface plasmons: i) extraordinary optical transmission through single and periodically structured subwavelength apertures [1] and ii) beaming of light through single apertures surrounded by periodic corrugations [2].

We will present the theoretical foundation for these phenomena and discuss the various dependences of the transmission [3] and emission profiles [4] on the different geometrical parameters defining the system, providing guidelines for the optimisation of these profiles for different possible applications, like lensing [5] and demultiplexing [6] among others. Finally, we will explore how these results found for metal surfaces can be exported to dielectric photonic crystals (PCs). We will show that, through appropriate corrugation of the PC surface, it is possible to obtain both enhanced transmission through slits in PC slabs, and strong beaming of light coming out of a PC waveguide.

[1] T.W. Ebbesen, H.J. Lezec, H.F. Ghaemi, T. Thio, and P.A. Wolff, Nature 391, 667 (1998).
[2] H.J. Lezec, A. Degiron, E. Devaux, R.A. Linke, L. Martín-Moreno, F.J. García-Vidal and T.W. Ebbesen, Science 297, 820 (2002).
[3] F.J. García-Vidal, H.J. Lezec, T.W. Ebbesen and L. Martín-Moreno, Phys. Rev. Lett. 90, 213901 (2003).
[4] L.Martín-Moreno, F.J. García-Vidal, H.J. Lezec, A. Degiron and T.W. Ebbesen, Phys. Rev. Lett. 90, 167401 (2003).
[5] F.J. García-Vidal, L. Martín-Moreno, H.J. Lezec and T.W. Ebbesen, Appl. Phys. Lett. 83, 4500 (2003).
[6] J. Bravo-Abad, F.J. García-Vidal and L. Martín-Moreno, Photonics and Nanostructures (in press).

**A2-IV.2** 09:00

OPTICAL NEAR FIELDS OF MULTIPOLAR PARTICLE PLASMONS

A. Hohenau, J.R. Krenn, G. Schider, H. Ditlbacher, A. Stepanov, A. Leitner, F.R. Aussenegg, Institute for Experimental Physics, Karl-Franzens-University and Erwin, Schrödinger Institute for Nanoscale Research, Universitätsplatz 5, 8010 Graz, Austria, W.L. Schaich, Department of Physics, Indiana University, Bloomington IN 47405, USA

Nanoscale noble metal particles are well known for their ability to sustain resonant electron plasma oscillations, so-called particle plasmons. This phenomenon gives rise to spectrally selective light absorption and scattering and to an enhancement of the local electric field. Due to these properties, metal nanoparticles are of high current interest for applications and fundamental research in fields as surface enhanced Raman scattering or nanoscale waveguides. Most investigations and applications focus on the dipolar resonances of such particles. However the particular near-field profiles and far-field scattering patterns of higher order excitations are of interest as well and might be advantageous for specific applications. In this presentation, we report on experimental and theoretical studies of multipolar optical excitations in prolate metal nanoparticles. The results of optical far-field extinction spectroscopy and optical near-field measurements on such particles can be qualitatively understood in a physical picture of standing plasmon-waves. The specific properties of the optical near-fields of the multipolar excitations compared to dipolar excitations are emphasized.

**A2-IV.3** 09:15

LONG RANGE SURFACE PLASMON PROPAGATION ON SILVER FILMS OF FINITE THICKNESS

Jennifer A. Dionne(a), Luke A. Sweatlock(a), Albert Polman(b), Harry A. Atwater(a), (a)Caltech, USA, (b)FOM Institute for Atomic and Molecular Physics, The Netherlands

With the ability to couple, confine, and guide light at subwavelength scales, surface plasmons have the potential to enable photonic devices to scale to truly nanoscale dimensions and to realize an integration density revolution similar to that experienced by silicon microelectronics. Surface plasmons bridge the dynamics of photons and electrons, opening the possibility to devices ranging from optoelectronic switches to biological sensors. In such applications, the lifetime and propagation length of the plasmon is of crucial importance, especially if integrated networks for nanoscale communication are to be realized. Here, results are presented on a symmetric planar geometry $SiO_2/Ag/SiO_2$ structure that supports long-range plasmon polariton modes. Particular attention is given to analyzing plasmon behavior on thin (less than 70nm) smooth silver films embedded in a symmetric dielectric environment. For such structures, the plasmon frequency was found to be at 3.7eV, with accessible wavevectors ranging from 0.01 through 0.5 1/nm for film thicknesses of 5-50nm. As Ag film thickness was decreased from 25-12nm, the top and bottom surface plasmon polariton modes became strongly coupled. Analytic dispersion results indicated a splitting of plasmon modes, with the higher energy mode exhibiting a negative group velocity for certain values of the wavevector. In addition, while plasmon propagation on semi-infinite films was not found to exceed 1mm, thin films exhibited propagation lengths approaching 1cm at near infrared wavelengths. Coupling from wavelength-scale to subwavelength scale waveguides at telecommunications wavelengths will be discussed and utilization of such results for potential designs of a plasmonic switching device will be explored.

**A2-IV.4** 09:30

TAILORING THE TRANSMITTANCE OF INTEGRATED OPTICAL WAVEGUIDES WITH SHORT METALLIC NANOPARTICLE CHAINS

Romain Quidant, ICFO-Institut de Ciències Fotòniques, Jordi Girona 29, Nexus II, 08034 Barcelona, Spain, Jean-Claude Weeber and Alain Dereux, LPUB, UMR-CNRS 5027, Optique Submicronique, UMR 9 av. Alain Savary, 21078 Dijon, France, Christian Girard, CEMES, UPR-CNRS 8011, 29 rue Jeanne Marvig, BP 4347, 31055 Toulouse, France

The manipulation of light fields at the submicrometre scale is needed for the miniaturization of integrated optical devices. Among the possible routes investigated, localized surface plasmon polaritons modes sustained by noble metal nanostructures offer promising properties to realize new generations of optical connections. However, the main drawback of purely metallic guiding structures is absorption which considerably limits the propagation lengths. An attractive alternative is then to combine dispersion properties of metal nanostructures with the guiding ability of lossless dielectric waveguides.

In this paper, we study the ability of noble metal nanoparticle chains supporting localized surface plasmons to tailor the transmittance of channel waveguides on wich they are deposited. The optical interaction between a micro-waveguide (MWG) and various arrangements of nanoparticles is first analyzed by means of numerical calculations based on the Green's dyadic formalism. For specific geometries of the particle chains, the transmission spectra of the composite device exhibits strong modulations in the optical range with appearance of a neat band gap. The results of an experiment inspired by this theoretical study are also discussed. The Photon Scanning Tunneling Microscope (PSTM) images recorded over a decorated MWG for two different incident frequencies are found to be in qualitative agreement with the theoretical proposal.

**A2-IV.5** 09:45

INFRARED SURFACE PLASMONS IN SELF-ASSEMBLED TWO-DIMENSIONAL SILVER NANOPARTICLE ARRAYS IN SILICON

H. Mertens, J. Verhoeven and A. Polman, FOM-Institute AMOLF, Amsterdam, The Netherlands

We present self-assembled two-dimensional arrays of silver nanoparticles embedded in amorphous silicon, fabricated by a sequential Si/Ag/Si electron-beam evaporation process, that exhibit surface plasmon resonances in the near-infrared. Si and Ag layers with thicknesses in the range 1-10 nm were evaporated onto a glass substrate in ultra-high vacuum at room temperature. This process leads to the nucleation and growth of oblate-shaped Ag nanocrystals, embedded in amorphous Si. Plan-view transmission electron microscopy shows Ag nanoparticles with major axes in the range 2-15 nm.

The surface plasmon resonance absorption peak, measured in transmission, shows a redshift for increasing Ag content, with a peak energy as low as 0.9 eV (wavelength 1.4 micron), found for the thickest deposited Ag films (2.2 nm). The redshift is a result of the combined effect of 1) the high refractive index of amorphous silicon, 2) the non-spherical shape of the nanoparticles and 3) interparticle coupling. For various evaporated silver thicknesses, the distribution of particle size, particle shape and interparticle distance was determined by transmission electron microscopy. Based on these characteristics, the absorption peak energies were calculated using a model for dipolar near-field interaction in which the nanoparticles are approximated as oblates. The calculated values are in qualitative agreement with the experimental results, and the observed redshift with increasing silver content is well described. By varying the evaporated silver thickness, the surface plasmon resonance energy can be shifted to 1.5 micron, enabling utilization of localized surface plasmon properties at telecom wavelengths.

**A2-IV.6** 10:00 -Invited-

NANOSHELLS: NANOSCALE MANIPULATION OF THE PLASMON RESPONSE

**Naomi J. Halas**, Department of Electrical and Computer Engineering and Department of Chemistry, Rice University, Houston TX, USA

The collective electronic resonance response, or plasmon frequency, of a metal nanostructure is dependent both on the constituent metal and on its shape. Systematic variations in the shape of metal nanostructures allows one to control and tune their near and far field electromagnetic properties. A particularly useful geometry for plasmon manipulation is a nanoshell, a nanostructure with a dielectric core and a metallic shell. In this topology the plasmon resonance depends sensitively on the relative inner and outer radii of the shell layer. Electromagnetic theory guides the specific design of these structures, within the constraints of the nanofabrication chemistry, to produce nanostructures with tailorable near and far field optical properties. New nanoscale geometries illustrate ways in which the nanoscale plasmon response can be manipulated and designed into a nanostructure. Generalization of the tailored plasmonic response to planar architectures is also achievable. One recent application that has emerged from our work is a utilization of the nanoshell geometry as a nanoengineered substrate on which the Surface Enhanced Raman Scattering (SERS) response can be precisely controlled and optimized to specific pump laser wavelengths. Tuning the plasmon response of nanostructures into the near infrared region of the spectrum allows for a variety of biotechnological applications, exploiting the infrared "water window" of highest physiological transmissivity.

10:30 **BREAK**

## Session V: Quantum dots and rods

## Session chair: H.A. Atwater (California Institute of Technology, Pasadena CA, USA)

**A2-V.1** 11:00 -Invited-

PHOTONIC CRYSTAL COMPONENTS FOR SOLID-STATE PHOTONIC QUANTUM INFORMATION SYSTEMS

Jelena Vuckovic, **David Fattal**, Edo Waks, Charles Santori, Dirk Englund, Hatice Altug and Yoshihisa Yamamoto, Edward L. Ginzton Laboratory, Stanford University, Stanford CA 94305-4088, USA

We have demonstrated indistinguishable sources of single photons based on quantum dots in one-dimensional photonic crystal micropost microcavities and have shown that such sources exhibit a large Purcell factor together with a small multi-photon probability. For a quantum dot on resonance with the cavity, the spontaneous emission rate is increased by a factor of five, while the probability to emit two or more photons in the same pulse is reduced to 2% compared to a Poisson-distributed source of the same intensity. We have also tested the indistinguishability of emitted single photons from such a source through a Hong-Ou-Mandel-type two-photon interference experiment, and found that consecutive photons have a mean wave-packet overlap as large as 0.81, making this source useful in a variety of experiments in quantum optics and quantum information.

By employing specially designed planar photonic crystal nanocavities instead of microposts, Purcell factor can be dramatically increased and even the strong-coupling regime can be reached. Planar photonic crystal cavities that we have developed exhibit large quality factors together with small mode volumes and have maximum field intensity in the high-index region, enabling strong interaction with quantum dot excitons. In addition to the demonstration of the solid-state cavity QED, this is also of importance for construction of single photon sources with improved efficiency, indistinguishability and speed, as well as for entangled photon sources on demand.

**A2-V.2** 11:30

HIGHLY DIRECTIONAL EMISSION FROM COLLOIDALLY SYNTHESIZED NANOCRYSTALS IN VERTICAL CAVITIES WITH SMALL MODE SPACING

J. Roither, W. Heiss, Institute of Semiconductor and Solid State Physics, University of Linz, 4040 Linz, Austria, D.V. Talapin, N. Gaponik, A. Eychmüller, Institute of Physical Chemistry, University of Hamburg, 20146 Hamburg, Germany

Colloidally synthesized semiconductor nanocrystals exhibit higher photoluminescence efficiencies than bulk materials. Nevertheless, it is difficult to achieve stimulated emission [1] and nanocrystal-based lasing [2] because of ultra-fast Auger recombination. Highly efficient light emitting devices for cw operation, however, can also be realized by the use of spontaneous emission, which is usually distributed uniformly in space. To obtain highly directional spontaneous emission from nanocrystals, they can be embedded in vertical cavities consisting of Bragg mirrors with modest reflectivities. Due to the wide spectrum of the spontaneous emission of nanocrystals, resonators with a long cavity length and thus a small mode spacing are more suitable than microcavities with resonator lengths in the order of the optical wavelength. Therefore, we use several micrometer thick pristine mica substrates on which Bragg interference mirrors are deposited on one side and nanocrystal films covered by metallic mirrors on the other side. From such devices with CdSe/CdS core/shell nanocrystals as active material highly directional room-temperature emission around 1.9 eV is achieved upon optical excitation. Due to the long cavity length, the emission spectrum shows up to 30 resonator modes within the nanocrystal luminescence band with a beam divergence smaller than 1.3°. [1] V. I. Klimov et al., Science 290, 314 (2000), [2] H.-J. Eisler et al., Appl. Phys. Lett. 80, 4614 (2002).

**A2-V.3** 11:45

RESONANCE-ENHANCED RAMAN SCATTERING AND ANTI-STOKES EMISSION FROM SPHERICAL MICROCAVITIES WITH CdTe QUANTUM DOTS

Yu.P. Rakovich, M. Gerlach, E.M. McCabe, J.F.Donegan, Department of Physics, Trinity College, Dublin, Ireland, T. Perova, A. Moore, Department of Electronic and Electrical Engineering, Trinity College, Dublin, Ireland, A.L. Rogach, Department of Physics and CeNS, University of Munich, Munich, Germany, N. Gaponik, University of Hamburg, Hamburg, Germany

Glass or polymer spherical particles of a few micron diameter can act as three-dimensional optical resonators making them potential candidates in the fabrication of microlasers. In this report we have studied the Raman and luminescence spectra of a novel microcavity-quantum-dot system consisting of CdTe colloidal quantum dots attached to a melamine formaldehyde latex microsphere of different sizes. In order to control the optical quality of the samples we utilize the sectioning property of confocal scanning microscope and experimentally studied the three-dimensional imaging of the microspheres demonstrating the possibility to locate any defect on the surface of the microcavity. Periodic structure with very narrow peaks in the luminescence spectra of a single microsphere corresponding to the whispering gallery modes was detected with strong emission into selected modes at high pump intensity. Strong coupling between photonic states of spherical microcavity and electronic states of CdTe quantum dots can be achieved simultaneously in both Stokes and anti-Stokes spectral regions using low intensity below bandgap excitation. This effect can be attributed to the strong field enhancement at the microcavity resonances. Shape of resonance peaks was analysed in wide spectral region and effect of absorption by CdTe quantum dots on quality factor of microcavity was studied. The cavity-induced enhancement of the Raman scattering allows the observation of Raman spectra from only a monolayer of CdTe quantum dots. Microspheres coated by chemically synthesized CdTe quantum dots should find use for photonic applications as a resonant system with well controllable wavelengths of the emission peaks in both Stokes and anti-Stokes spectral regions.

**A2-V.4** 12:00

OPTICAL AND STRUCTURAL PROPERTIES OF SELF-ORGANIZED GROWN ZnO NANORODS

D. Forster, F. Bertram, Th. Hempel and J. Christen, Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany, R. Kling, C. Kirchner, Dept. of Semiconductor Physics, Ulm University, Ulm, Germany, A. Waag, Institute of Semiconductor Technology, Braunschweig Technical University, Germany

ZnO nanosized material as promising candidate for UV nanolasers and optoelectronic devices has attracted increasing attention in recent years. Especially the intentional control of morphology plays the decisive role for the fabrication of self-organized grown ZnO nanostructures.

The ZnO:Ga nanorods on a-plane sapphire substrate have been grown by MOCVD. During the growth a rough ZnO nucleation layer is deposited on the sapphire. The nanorods exhibit an almost uniform shape (length ~2µm) with a hexagonal base plane (diameter ~100nm), a wire axis in c-direction and tapered towards a sharp tip. The density of the rods over the sample surface is about 2.104cm-2. A direct correlation of structural and optical properties of ZnO:Ga nanorods has been achieved on a microscopic scale using highly spatially and spectrally resolved cathodoluminescence (CL). The laterally integrated CL spectrum is dominated by a donor bound exciton (BE) emission (FWHM = 3.2meV). An additional spectral line (FWHM = 10.3meV) from deeply bound excitons (DBE) at lower energies can be obtained. Monochromatic CL images show a BE emission from the nanorods and a strongly localized luminescence from the DBE originating from the seed layer. Local spectra along a single rod display a slight blue shift of luminescence towards the tip of the rod.

**A2-V.5** 12:15

OPTICAL GAIN IN SILICON NANOCRYSTALS GROWN BY DIFFERENT TECHNIQUES

M. Cazzanelli, D. Navarro-Urriós, F. Riboli, Z. Gaburro, N. Daldosso, and L. Pavesi, INFM-Dipartimento di Fisica, Università di Trento, via Sommarive 14, 38050 Povo (Trento), Italy

The amplified spontaneous emission from Si nanocrystals grown by a wealth of different techniques has been observed in different waveguiding samples. The material gain value has been extracted from the modal gain measured with the time-resolved-variable-stripe-length (TRVSL) technique by taking into account the propagation losses and the modal confinement factors of the embedding waveguide structure. A first tentative to understand the physics behind this phenomenon has been attempted by looking at the material gain trend versus some sample's structural parameters. An interesting dependence on the silicon nanocrystals' mean radius as well as on the optical confinement factor and active material refractive index has been observed. The experimental data are interpreted in the framework of a four level model based on the balance of Auger non-radiative recombination and stimulated emission from silicon nanocrystals embedded in SiO2, where the interface between the Si-nc and the embedding matrix is playing a critical role.

12:30 **LUNCH**

## Friday, May 28, 2004 Afternoon

### Session VI: Nanoscale emitters

### Session chair: L. Pavesi (University of Trento, Povo, Italy)

**A2-VI.1** 14:00

Si/Si:Er MULTI-NANOLAYERS FOR SILICON PHOTONICS

N.Q. Vinh, M.A.J. Klik and T. Gregorkiewicz, Van der Waals-Zeeman Institute, University of Amsterdam, The Netherlands, B.A. Andreev, Institute for Physics of Microstructures, Nizhny Novgorod, Russia

Si/Si:Er multi-nanolayer structures grown by sublimation MBE technique exhibit unusual optical properties which make them very interesting for photonic applications. In particular, our recent investigations have proven preferential formation of a single type of optically active Er-related center in these structures. In that way one of the basic requirements for development of optical amplifier based on Si:Er is finally fulfilled. Moreover, low-temperature high-resolution spectroscopy shows that the photoluminescence of the dominant center is characterized by an ultra-narrow linewidth of ∆E ≤ 10 μeV. This represents most probably the smallest value ever measured for any emission band from a semiconductor host. The extremely small linewidth indicates a large absorption cross-section, and that opens new hopes for the possibility to realize optical amplification in Si:Er.

In the contribution, we will review properties of Er-related optical centers formed in the multi-nanolayer structures as revealed by high-resolution time-resolved photoluminescence, excitation and magneto-optical spectroscopies. In particular, the following results will be presented:

* Fast components appearing in the decay kinetics at high pumping rate
* The percentage of optically active Er-related centers in comparison to the total concentration of Er atoms.
* Excitation cross-section and its variation upon excitation mode (band-to-band pumping compared to illumination with photons of subbandgap energy). Based on the experimental findings, potential of Si/Si:Er nanolayers for silicon photonics will be discussed.

[1] N.Q. Vinh et al. Phys. Rev. Lett. 90, 066401 (2003).
[2] M.A.J. Klik et al. submitted for publication

**A2-VI.2** 14:15

THE PECULIARITIES OF LIGHT PROPAGATION THROUGH SELF-ORDERED POROUS ANODIC ALUMINA MATRIX

N.V. Gaponenko, I.S. Molchan, Belarusian State University of Informatics and Radioelectronics, P. Browki St. 6, 220013 Minsk, Belarus, A.A. Lutich and S.V. Gaponenko, Institute of Molecular and Atomic Physics, National Academy of Science, F. Skaryna Ave. 70, 220072 Minsk, Belarus

Porous anodic alumina (PAA) is a prospective material in viewpoint of nanophotonics application due to its self-ordered structure with the structural geometric sizes comparable to wavelengths of optical range. PAA membranes have optical transmission up to 97% at normal incidence. The infiltration of PAA matrix with lanthanide-doped films by sol-gel method allows for strong enhancement of lanthanide luminescence. Strongly enhanced luminescence of Er, Yb, Eu, and Tb in such structures was observed [1, 2]. One reason of luminescence enhancement is multiple scattering of exciting light by PAA matrix that was discussed recently [3]. In this paper, we concern another consequence of the light scattering into PAA membrane resulting in occurrence of spatial anisotropy of emergent light.

Three peaks on the scattering indicatrices were observed with the maximum one along the pore axes. Mechanism of the peak formation is interpreted as follows. Light diffusely scatters on the defects of PAA structure under non-isotropic density of photon states (DOPS) conditions. Probability of light scattering in certain direction is proportional to the DOPS in this direction [4]. DOPS has a maximum value in the direction along pores and a minimum in the perpendicular directions. Therefore, light mainly scatters in the direction along pore axes.

[1]N.V. Gaponenko, J.A. Davidson, B. Hamilton et al, Appl. Phys. Lett. 76 (2000) 1006
[2]N.V. Gaponenko, J. Appl. Spectroscopy 69 (2002) 1
[3]I.S. Molchan, N.V. Gaponenko, R. Kudrawiec et al, J. Electrochem. Soc. 151 (2004) H16 4. S. V. Gaponenko, Phys. Rev. B 65 (2002) 140303

**A2-VI.3** 14:30

NON-LINEAR OPTICAL BEHAVIOUR OF A NANOSCALE Si-LAYERED SYSTEM

Z.T. Kuznicki, Laboratoire PHASE, CNRS UPR 292, 23 rue du Loess, 67037 Strasbourg cedex 2, France, H.J. Lezec, ISIS, ULP, 8 allée Gaspard Monge, 67083 Strasbourg cedex, France and Y. Takakura, TRIO/LSIIT (UMR 7005), BP 10413, Bd Sébastien Brant, 67412 Illkirch, France

We have observed that the optical functions of a nanoscale Si-layered system [1] depend on both the flux and the wavelength of the incident light. For example, over the 300-800 nm range, the integrated reflectivity can vary by more than 20% as a function of intensity and more than 50% as a function of wavelength.

The nanoscale Si-layered system was formed by ion-beam implantation and adequate thermal treatment [2]. It contains a free-carrier surface reservoir, which is delimited by the silicon surface and a buried c-Si/a-Si interface (determined by a valence band offset) [3]. The optical behaviour seems related to the local free-carrier population rather than to the intrinsic properties of the Si material and fabricated interfaces. When the carrier lifetime is long enough, the photogenerated carriers are stored in entirety at the surface zone, forming a two-dimensional system of metallic density. As a result, corresponding optical features are expected be dominated by the surface population of this dynamic quasi-metallodielectric interface, with the probing light influencing measured functions leading to their self-amplification or self-attenuation. Though the devices characterized in present study are designed as next-generation solar cells, their strong nonlinear optical behavoir suggests they shows promise for applications in other areas such as electro-optic modulation and all-optical switching.

[1]Z.T. Kuznicki, Applied Physics Letters 81, 4853(2002).
[2]Z.T. Kuznicki, Multi-interface novel devices/ model with a continuous substructure, Chapter 8 of the book "3rd Generation Photovoltaics for High Efficiency through Full Spectrum Utilization", Ed. A. Luque, A. Marti, Institute of Physics Publishing, Bristol, UK, 2003.
[3]M. Ley, Z.T. Kuznicki, V. Svrcek, Applied Physics Letters 82, 4241(2003).

**A2-VI.4** 14:45

NANOPILLARS PHOTONIC QUASICRYSTAL ADD-DROP FILTER

D.N. Chigrin, A.V. Lavrinenko, J. Romero-Vivas and C.M. Sotomayor Torres, University of Wuppertal, Department of Electrical, Information and Media Engineering & Institute of Materials Science, Wuppertal 42097, Germany

Nanopillars photonic quasicrystals (PhQCs) exhibit most of the properties attributed to photonic crystals (PhCs). However in some cases optical devices, based on PhQC, can deliver better performance with respect to the PhC analogies. In this presentation, we propose a design of an add-drop filter based on an octagonal PhQC. Due to the high rotational symmetry (8-fold) of the octagonal PhQC, a microcavity with four-fold degenerated hexapole modes can be design. Two hexapole modes remain degenerated even after introduction of two waveguide channels into the system by removing several rows of nanopillars. This opens a favorable condition for add-dropping effect. In contrast to the similar add-drop filter design based on PhC, the presented PhQC design does not require special adjustments, e.g., fine tuning of specific nanopillars radiuses or refractive indices, significantely reducing technological challenges of practical realization of the structure.

We present a detailed FDTD study of optical properties of PhQC based cavities, waveguides and add-drop filters for different dielectric constants of nanopillars. A sizable photonic bandgap for TM polarization is found for dielectric constant 5.0, which is about two times smaller than the dielectric constants of typical PhC devices. An add-drop filter with the quality factor close to 700 and the dropping efficiency better than 95% is design and numerically characterized for dielectric constant 5.0.

15:00

CLOSING REMARKS

H.A. Atwater, H. Lezec and A. Polman